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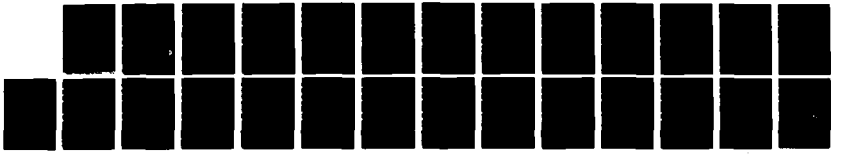

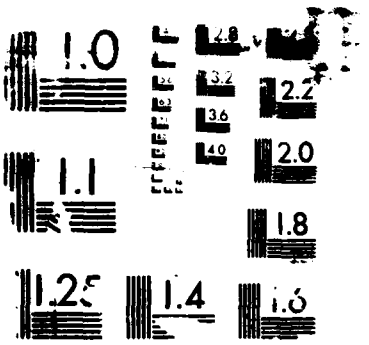
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Aerodynamics Technical Memorandum 389

AUSTRALIAN AERODYNAMIC DESIGN CODES FOR AERIAL TOW BODIES (U)

by

N. MATHESON

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AUSTRALIAN AERODYNAMIC DESIGN CODES FOR AERIAL TOW BODIES (U)

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N. MATHESON

SUMMARY

An overview is presented of the design codes developed in Australia that are directly applicable or related to the Aerodynamics of towed bodies.

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1. INTRODUCTION

In the 1984 and 1985 reports of meetings of TTCP Panel HTP-1, which deals with aerial targets, it was recognised that there was a need for a complete and well documented approach for their aerodynamic and structural design. It was noted that while there were a number of relevant computer programs and design methodologies available, their direct applicability to towed targets was uncertain.

In view of the continuing need for increasingly sophisticated towed targets, often as an alternative to costly subscale targets, a collaborative activity was undertaken to:

1. review the availability and applicability of existing design codes for the free flight phase of deployed aerial tow bodies in the subsonic and supersonic flight regimes; and

2. recommend either an existing design approach or cooperative action to provide a satisfactory capability.

In this report, an overview of the design codes developed in Australia that are directly applicable or related to the aerodynamics of towed bodies is presented.

2. COMPUTER BASED AERODYNAMIC DESIGN CODES DIRECTLY APPLICABLE TO TOWED BODIES

As far as can be ascertained, four different computer programs have been developed specifically to predict the aerodynamic behaviour of towed bodies (targets) in various phases of deployment[1,2,3,4]. These programs and associated analyses are reviewed in the following sections.

2.1. Steady State Model Based on Glauert's Equations

The earliest program was developed in the late 1960's to predict the steady state separation of a tug (aircraft) from a body towed at its centre of gravity in straight and level flight with a constant velocity[1].

2.1.1. Analysis and computer code

The equations developed were based on Glauert's equations[5], derived using the concept of a 'body of zero drag', which define the shape of an imaginary towing cable between this body and the tug (aircraft). For a 'weightless' cable the tension in the cable is constant along its length. Details of Glauert's analysis are given in Refs 1 and 5.

The computer program was initially developed for a towed body without lateral displacement, the cable weight was assumed to be negligible compared with the cable drag, and the aerodynamic force per unit length of cable was assumed to be at right angles to an element of the cable.

The analysis was extended to a towed body laterally displaced from the tug by assuming the plane of the tow cable is inclined at an angle to the vertical plane containing the velocity vector of the towing aircraft.

To enable the equations defining the cable shape to be evaluated, the tension in the cable and its direction at the towed body must be known. Cable tension was

determined as the resultant of the lift, weight and drag forces of the tow. The trim incidence of the towed body was obtained by solving the pitching moment equation derived by assuming the tow has no rotational accelerations. Knowing tow incidence, then the lift and drag can be calculated, and hence the cable tension and its direction at the tow.

The program was written in Fortran for an IBM 7090 computer and a full listing is available[1].

The program was developed to predict the separation performance of Tonic Mk2 and Mk5, and Turramurra targets. Details of these targets are given briefly in Appendix 1. Relevant data describing the aerodynamic characteristics of the tows in the program were obtained from wind tunnel tests of full scale models.

2.1.2. Validation and comments

Although not fully validated, results predicted from the program for the Turramurra in the Mach no. range from 0.36 to 0.63 on cables varying from 45 m (150 ft) to 100 m (330 ft) were within 6% of experimental trails results.

In the case of Tonic with an offset tow, the error in the fore and aft separation was of the order of 4%, but in the vertical and lateral separations the error was about 10%.

The computed results were strongly influenced by the cable drag data input to the program.

The program is quite simple and it has provided a quick and convenient means for predicting steady state tug - tow separation, and is applicable for a range of cable lengths, Mach numbers, altitudes, and tow configurations.

The program is limited to the two dimensional steady state case and does not deal with stability. In its present form it is limited to targets towed at their C of G and cable tension variations with length cannot be assessed.

2.2. Early Dynamic Model and Stability Analysis

In the early 1970's the equations for the steady state cable shape developed from Glauert's equations[1,5] were used as the initial conditions in a six-degree-of-freedom simulation model and stability analysis[6]. The cable tension and direction were determined from the known steady state aerodynamics of the tow assuming no out of balance pitching moment. These equations were used to derive the small perturbation equations for both a non-extensible and an extensible cable so that the change in cable tension and its direction could be determined for a small change in tow position. The effects of lateral cable displacement, cable drag, and cable mass were taken into account.

The six-degree-of-freedom model was set up by describing the motion of the towed body (and cable attachment point) using the normal equations of motion for a near symmetrical aerodynamic body[7]. The equations describing the velocity of the cable attachment point, which is the vector sum of the velocity of the C of G and the rotational velocity, were derived and integrated to give the position of the attachment point at a given time in terms of the initial simulation position of the attachment point.

The cable tension and direction were then derived as a function of the motion of the cable attachment point using the steady state cable shape equations and the small perturbation equations in a simple iteration technique. Lateral drag effects were included. The cable tension was resolved into body axes for use in the equations of motion to complete the dynamic and cable equations necessary to set-up the simulation model.

The six-degree-of-freedom small perturbation stability matrix was then derived from the previous equations so that the effects of various parameters on the stability of the system including the effects of attaching the cable to the towed body at points other than its C of G., could be investigated.

The equations have not been programmed to form a simulation model. Consequently the equations have not been applied to a towed body and the analysis has not been validated.

2.3. Initial Dynamic Model of Target and Cable During Deployment (HIPATS-1)

Later work on the mathematical modelling of towed targets concentrated on the development of a two dimensional dynamic model of the deployment phase of the High Performance Aerial Target System (HIPATS)[2,3,4]. In the first attempt in 1979 a model was partially developed by personnel at the Advanced Engineering Laboratories. This model was intended to assist with the design of HIPATS-1 which was being developed in Australia at that time. Brief details of HIPATS-1 are given in *Appendix 2*.

The model was to be used to calculate the time history of the forces, accelerations, velocities and displacements of the target as it was deployed. The furled target is unstable on ejection and it has a high drag which can result in a separation velocity that can lead to transient loads of up to 12 kN (2700lb) on the cable as the target is accelerated up to the speed of the aircraft and taken in tow.

The approach taken was to calculate the dynamic behaviour of lumped mass elements joined by elastic links. Drag forces were calculated by associating a massless cylindrical body aligned with the cable with each element. The instantaneous forces from drag, elastic links and gravity were calculated and a time stepped integration procedure was used to calculate a series of accelerations, velocities and positions for each element.

Cable payout was also included in the model. Parameters were calculated for all elements known to have left the canister and the position of the next element to be paid out was calculated relative to the canister. When this element had been paid out logic within the program incremented the number of elements paid out and applied the test for having left the canister to the next element. Thus when the run began, dynamic behaviour of a single element was considered, which resulted in a considerable saving of processing time.

The model was programmed in BASIC-PLUS to run under the RSTS/E operating system on a PDP 11/40 computer.

Calculations of cable behaviour were achieved for partial cable payouts. However, in almost all cases the model eventually became unstable before payout was completed and large out-of-phase oscillations were calculated for adjoining elements. The model also required an unacceptably long run time unless the number of elements for a 300m cable, for example, was reduced to about 10.

Owing to the stability and long run time problems encountered the model was not completed. There are no publications relating to the work and no program listings are available.

2.4. Quasi-Static Model of Sabot (Target) and Cable During Deployment (HIPATS-1A)

Owing to the failure of the Dynamic model reviewed in section 2.3, a two dimensional Quasi-Static Model[2] was developed in 1983 to model the deployment and flyback of improved versions of HIPATS, designated HIPATS-1A and HIPATS-2. Brief details of these target systems are given in Appendix 2.

The purpose of this model was to assist with the engineering design and development of these target systems pending completion of a more rigorous dynamic model. Determining the loads on the cable and on the structural parts of the system as the sabot (module) is snatched up to speed was particularly important.

2.4.1. Analysis and computer code

The basic equations used in the model of the cable were derived from a static free body analysis of a small curved element of the cable. From these equations the steady state trail angle of the towline was determined.

Cable weight was taken into account in the derivation of the equations but was neglected in subsequent analyses. It was also assumed that rapid changes in cable shape do not occur and the axial cable acceleration was taken as being equal to the magnitude of the target acceleration. These assumptions are most in error where the cable curves down to meet the sabot (target). The magnitude of the relative airflow vector for all cable elements was also assumed to be the same as for the target. This can lead to errors during the early part of deployment and at low deployment speeds where the vertical velocity component is relatively high and the cable shape varies more quickly.

For the sabot (target) itself, previous trials data for HIPATS-1 had indicated that some of the dynamic terms in the equations were small, particularly at higher deployment speeds. Consequently sabot (target) translational dynamic terms are included but rotational terms are neglected. The lift and induced drag were assumed to act through the centre of pressure and the sabot normal to its longitudinal axis, and the profile drag was assumed to act through the C of G of the sabot. The sabot pitch angle was computed in the program assuming the sabot is in static equilibrium.

The model uses a 'shooting method' algorithm whereby a quasi-static cable shape is projected forward from the target end of the cable to the canister on the aircraft. Interpolation between two 'shots' is used to choose the best quasi-static cable shape between the target and canister and to estimate the tow cable tension vector at the target. This vector is then applied to the target together with the remaining forces on the target and the pitch angle for static equilibrium is then obtained iteratively. Target aerodynamic forces are recalculated at the new pitch angle and airspeed and a new cable shape found as before.

Two numerical factors had to be incorporated in the program to make it run. First, to prevent program failure during the early stages of cable payout (first 5m) the drag of the sabot had to be increased artificially. Fortunately, calculations showed that conditions at snatch, including cable tension, were not very sensitive to this increased drag. Second, the tow cable velocity at the aircraft had to be

multiplied by a correction factor, which was modified after each iteration, to ensure that the end of the cable at the canister does not move away from the canister as the cable shape changes.

The model was programmed in BASIC to run interactively under the RSTS operating system on a PDP 11/40 computer.

2.4.2. Cable stability

Cable and target dynamic stability were not modelled. However, the condition necessary to preclude towline oscillations for steady state operation according to the equation

$$V/(T/m)^{0.5} = \text{a constant, theoretically} = 1.0$$

where V = freestream velocity, T = cable tension, m = cable mass per unit length was included in the model. A constant of 1.5 was used because this value has been found to give good results in practice.

2.4.3. Cable stress wave analysis

The stress distribution in the two cables during 'snatch' was studied to determine the factors which effect the peak stress in the cable. The analysis followed the work of Brinkworth[8] but was modified to include the strain energy absorbed by the cable as it straightens, which was very important.

This analysis was used to show that the peak cable tension could be reduced by approximately 50% by including a length of tear webbing (strap) at the sabot/cable junction.

2.4.4. Validation and comments

Values of target longitudinal and lateral separation and separation velocity calculated from the model have been compared with trials data for the HIPATS-1.

In the later stages of payout the agreement between calculated and trials data was reasonable, although there is some discrepancy between the times required to payout a given length of cable. An example of the agreement is shown in table 1.

Table 1 - Comparison of experimental and model results

Tow cable length L = 40 m:

	time (sec)	z coord (m)	Sepn. vel (m/sec)
Trial	1.9	-5	45
Model	1.3	-10	46

Tow cable length L = 280 m

	time (sec)	z coord (m)	Sepn. vel (m/sec)
Trial	5.9	-79	77
Model	4.8	-78	80

This approximate quasi-static model has the advantages of being much simpler than a full dynami . model so that computer run time is much shorter. It also includes an assessment of cable oscillations and stress transients.

The model has the disadvantages of requiring a numerical factor to artificially increase the drag of the sabot to allow the program to run during the early states of cable payout where the assumptions are invalid, and it also requires another numerical factor to adjust the cable velocity to keep the cable attached to the canister.

However, the model has been used successfully to assess the effects of various changes in the deployment configuration and system design parameters, and to assist with the engineering design of both HIPATS-1A and HIPATS-2.

A program listing is available but it is not well documented. No further development of the model is planned.

2.5. Dynamic Model of Sabot (Target) and Cable During Deployment

Just after the quasi-static model[2] was developed, a more complex two dimensional model of the dynamics and kinematics of the sabot and cable from ejection to just before snatch was developed[3] to assess the effects of changes in the deployment configuration and in the design parameters.

2.5.1. Analysis and computer code

The motion of the cable and sabot were described in terms of the normal and tangential velocity u, and v relative to the tug (aircraft), the angle of the cable to the horizontal, Phi, and the tension in the cable, T, which are all functions of time and position, described by the distance, s, along the cable from the sabot. The tug was assumed to fly horizontally at a constant velocity (deployment velocity) and cable and sabot lift, drag and weight were taken into account.

By considering the velocity and forces on an element of an inextensible flexible cable, four partial differential equations were developed in four unknowns. At the ends of the cable, different boundary conditions apply where some of the variables are known.

By considering the forces and moments at the cable attachment point on the sabot, three equations are obtained in five unknowns, the four cable variables and the angle of the sabot to the horizontal, Theta. However the model was simplified by taking Theta = constant so that the moment on the sabot at the point of attachment (C of G) is zero (non-rotating sabot). This eliminates one equation and one unknown leaving two equations and four unknowns at the sabot end of the cable.

It was assumed that the cable was made up of a finite number of points, N, which gave 4N-1 equations and 4N-1 unknowns. Due to the nonlinearity of the partial differential equations, numerical methods involving finite difference approximations together with a multivariable extension of Newton's iteration technique, were employed to solve them at discrete time intervals. Care was taken in choosing the finite difference approximations as a poor choice could have led to instability and failure of the numerical technique. At the sabot end, small time steps (and hence length steps) were required as cable payout commenced, but, this led to an excessively large amount of computation to model the 300m of cable. To meet the requirements of fine time steps at the sabot end of the cable, without an

extensive number of steps over the whole cable, the time steps were increased geometrically as the cable was payed out. Tests were applied at the end of each iteration to check for numerical convergence and stability.

The model was programmed in Fortran to run on an IBM 370/3033 computer. Solution of the equations at discrete time intervals resulted in estimates of the position, angle, velocity and tension at points on the cable and at the sabot as the cable was payed out. This allowed the separation velocity at snatch, the tension in the cable at the canister, the tension on the sabot during flyback, the angle of the cable at the sabot during flyback, and the acceleration of the sabot, to be assessed as design parameters were varied.

2.5.2. Validation and comments

The model has been checked for operation and consistency but it has not been validated against flight data. However, it is planned to do this at the earliest opportunity.

Some difficulties have been encountered with the model. In general, if the input design parameters had values which allowed the sabot to drop quickly after ejection so that the cable angle became large, then the numerical techniques became invalid and the program failed. To overcome these problems a numerical factor had to be incorporated in the program to artificially increase the drag of the sabot before it would run. It should be noted that a similar increase in drag had to be incorporated in the quasi-static model[2] to make that program run. The lack of inclusion of sabot rotation effects could have caused this problem.

The effects of cable elasticity, which can effect the tension in the towing cable, have not been included. Similarly a stress wave analysis at snatch has also not been considered. Thus, the effects of the shock strap (tear webbing) incorporated in some HIPATS cannot be modelled.

Although the stability of the cable and the sabot were not considered directly, the effects of displacing them from their 'equilibrium' position can be investigated.

2.6. Dynamic Model of Sabot (Target) and Cable During Deployment with Controlled Payout (HIPATS-2)

The model[4] is essentially an extended version of the previous dynamic model[3] but is aimed at simulating HIPATS-2 (see Appendix 2) before, during and after controlled flyback of the module. Cable configurations before and after flyback represent equilibrium (steady state) conditions.

2.6.1. Analysis and computer code

The four non-linear first-order differential equations derived by considering an element of the cable were the same as the equations used in the previous model[3], and the same assumptions were made in their derivation. Module rotation was not considered.

To obtain a solution to the full time-dependent dynamic equations of motion numerical techniques were used and the initial conditions were defined by the steady state solution.

The computer programs to perform the numerical calculations were written in Fortran 77 and a complete listing is available. As in the previous model[3], the design parameters were treated as variables so that design changes to the system could be investigated easily.

2.6.2. Steady state solution

The module was assumed to settle in an equilibrium position with a specified clearance (4 to 5m) from the aircraft after detection of the shock of the strap (tear webbing) snatching into the canister attachment during the 5 second delay before controlled cable payout.

The steady state solution of the partial differential equations was obtained using a 4th order Runge Kutta method. The same technique was used to determine the steady state cable shape and tension at completion of payout to a given cable length.

The computer program was checked for a zero displacement velocity (zero aircraft speed, cable hangs vertically), and at a very high deployment velocity and found to work satisfactorily.

2.6.3. Dynamic solution and stability analysis

The full time-dependent equations of motion were solved initially using an explicit finite difference technique involving both time and spatial derivatives as the subjects, and both forward and backward differences. Unfortunately, this method suffered from inherent instability and it was abandoned in favour of an implicit 'shooting method' using forward differences with spatial derivatives as the subjects.

In the implicit scheme, a value of the tangential velocity, U_0, and the normal velocity, V_0, at the module end of the cable were estimated (intelligent guess) and then the cable angle and cable tension at the module were calculated from the two-degrees-of-freedom free-body equations of motion of the module. From these values, the dynamic equations of motion were used in a forward difference scheme, with only spatial derivatives as the subject, to 'shoot' up the cable simultaneously calculating values of the four cable parameters u, v, Phi and T. The cable payout velocity was assumed to be constant in the analysis. The values of U and V calculated at the aircraft/cable attachment point were then compared with the values specified. For example, U_N = velocity at payout (last cable element at aircraft) and $V_N = 0$ (since cable is assumed to be wound out tangentially from a drum). If both these parameters do not correspond then a quasi-Newton iteration technique is used to modify the estimated values of U_0 and V_0 by a small amount (first element of the cable at the sabot) and the process is repeated until the calculated values of U_N and V_N agree with those prescribed. In this way the tension and velocity distribution along the cable and the shape of the cable are obtained.

A stability analysis of the finite difference scheme was carried out to determine its validity for a constant length of cable according to the criteria:

1. system should remain in equilibrium (as given by the steady state solution) when analysed over a period of time with the time-dependent equations of motion in the finite difference form;

2. after being displaced from equilibrium (as given by the steady state solution) the system should return to its equilibrium position, and remain there, when analysed over a period of time using the time-dependent equations of motion.

The calculation technique was able to satisfy both criteria and it was therefore taken as being correct.

2.6.4. Validation and comments

The program has not been validated against experimental results, but has been checked for consistency as indicated previously.

Some difficulty has been experienced during the early states of simulated motion where the cable is short. If a small time step delta τ = 0.1 to 0.5 sec. was used, the quasi-Newton iteration did not always converge. If longer time intervals were used some calculated parameters (normal velocity) did not correspond. For example, using delta τ = 1.0 sec and 0.75 sec, leads to lack of parameter correspondence at times such as τ = 3.0 sec. Thus the calculation technique may not provide a good representation of the transient (short term) solution during flyback. However, fewer difficulties were experienced with low payout velocities (0.5 m/sec).

During cable payout, a compromise to the solution in terms of stability, accuracy and computation time has usually been necessary. It may be difficult to eliminate this compromise due to the relationship between cable payout velocity, cable element length, and the time step.

Improvements could be achieved by introducing a more sophisticated iteration technique (than the quasi-newton method) which will predict convergence at all stages during cable payout.

However, the program for both the steady state and dynamic analyses can easily be used to investigate design changes to assist with the actual design of towed target systems.

3. COMPUTER PROGRAMS RELATED TO THE AERODYNAMICS OF TOWING CABLES

Brief details of several other codes related to towing cables are given in the following section.

A steady state and a time dependent model have been developed[9-15]. These models were written in Fortran IV for a DEC System-10 computer at the Aeronautical Research Laboratories (ARL). This computer has now been replaced by an ELXSI, but the programs have not been fully implemented on this machine and considerable effort would be required to make them operational.

3.1. Steady State Model

A steady state three-dimensional model of a flexible cable to suspend a body from a point moving at a constant velocity was developed[9,10] in the late 1970's. The differential equations of motion were derived for a cable immersed in a Newtonian fluid, and solved using a second order Runge Kutta method (in certain simple cases analytical solutions were obtained). Small angle approximations were used so difficulties can be expected if the model is used to simulate cables with large curvatures.

The model has been used to examine the effect of winds and currents on a cable used to suspend a sonar in the sea from a helicopter. When the sonar was below the sea surface the solution was first obtained for that part of the cable in

water, which then gave the boundary conditions for the solution to that part of the cable in air. Skin friction, cable twist, induced mass, cable elasticity and sea waves were not considered. A modified version[13] of this model has been used to estimate the steady state two-dimensional position of a pitot probe (approx. 1.5m 5(ft) long), trailed on a cable (approx. 46m (150 ft) long) behind a helicopter flying at constant speeds up to 120 knot. The predicted positions agreed well with experimental results.

The modified model[13] has recently been extended to streamline bodies by considering skin friction and pressure drag separately. This model has been used to assess the steady state performance of a Rushton Low Level Height Keeping Target designed to operate at an airspeed of 300 knot. The position of the target, the shape of the cable, and the cable tension were all predicted for airspeeds between 250 and 350 knot, cable lengths between 1500 m (5000 ft) and 6000 m (20,000 ft), and cable diameters ranging from 1.2mm (0.05 in) to 2.5 mm (0.10 in). This work has not been published.

3.2. Time Dependent Model

A three-dimensional time-dependent model of a cable towing a body has also been developed. This model is a more elaborate version of a model that was developed[16] in the early 1970's and has been used to study the behaviour of a sonar deployed from a helicopter[14,15]. Full details of the model have not been published but information on an early version, without cable payout, is given in Refs 14 and 15.

The cable is divided into a number of sections whose lengths, which may all be different, are specified by the user taking into account the desired accuracy and execution speed for a given simulation. The body (sonar) forms the end section of the cable. For each section, the mass is assumed to be concentrated at the centre of gravity which is assumed to correspond to the section mid-point, except for the end section where the body is located. The point masses were then considered to be linked by weightless rigid rods (links), joined sequentially to one-another by frictionless pivots.

By considering the effects of gravitation, tension, and fluid forces (including buoyancy) on the motion of each link and the body, a set of differential equations was derived.

Small angle approximations were used for the relative angular displacements of joined links. This could present problems when simulating cables with large curvatures. Cable payout and reel-in was simulated by keeping the number of links constant while allowing their length, and hence their mass, to change. Pitching motion of the body (sonar) is not included and the cable is assumed to be inelastic.

Tensions in the links were first obtained from n simultaneous algebraic equations in the n unknown link tensions. These equations were in tri-diagonal form and were solved using the Gauss elimination method. The second order differential equations in pitch and roll orientation of each link (2n equations) were then solved using a second order Runge Kutta method.

The main difficulty with this model is that numerical instability can occur when the cable is short because of the large differences in link mass due to the large end link mass (body). This can be overcome by carefully setting the link lengths, or by combining links under certain circumstances.

The model has been checked for consistency but it has not been validated against experimental data.

A simple two-dimensional form[11,12] of this model has been used to investigate the stability of a sonar (body) as it was raised on a cable from just above the surface of the sea to a helicopter either hovering or travelling slowly. In this analysis the cable was assumed to be rigid and weightless with a heavy body (sonar) attached to one end. The effects of cable pay-out and reel-in were taken into account.

3.3. Miscellaneous Studies

Several other studies have also been made which relate to towed bodies[17,18] but no computer codes have been generated.

In 1961, a theoretical analysis was made of the motion of a long cable moving horizontally towing a target after there was a large reduction in drag, for example when it is severely damaged or becomes detached[17]. Time histories of the motion of the cable were deduced.

An approximate analytical method for predicting the position of a paravane (inverted glider) towed on a cable has also been developed[18]. The differential equations of motion were derived and integrated after applying order to magnitude arguments. Theoretical predictions of cable shape and paravane position compared reasonably well with the positions derived from photographs taken during flight tests.

4. COMPUTER PROGRAMS RELATED TO THE AERODYNAMICS OF TOWED BODIES (TARGETS)

In the computer codes developed for towed bodies (targets) the aerodynamics of the body have been expressed in terms of aerodynamic coefficients. This information can be produced by wind tunnel tests of appropriate models, or by using computer codes (CFD), or possibly from flight trials.

In the following sections the programs available that are related to the aerodynamics of the towed body itself are very briefly considered.

4.1. Missiles and Streamline Bodies

The CFD work carried out at WSRL related to missiles and streamline bodies was reviewed[19,20] in 1980. The CFD work was based on finite element methods and was centred on two programs developed in the United States, the first by the Naval Surface Weapons Centre (NSWC), and the second, known as Digital Datcom, which is based on the USAF Stability and Control DATCOM.

The NSWC code enables data for preliminary design and for assessment of existing and proposed missiles and streamline bodies to be predicted quickly at both subsonic and supersonic speeds. Consequently, the program can be used instead of wind tunnel tests when good, but not precise, aerodynamic data are needed. It is also applicable to general body and wing geometries at angles of attack up to about 15 degree.

A computer code to predict the aerodynamic characteristics of slender bodies of revolution with a turbulent boundary layer at small incidence has also been developed[21]. This program can be applied to a wide range of slender axially symmetric bodies.

4.2. Aircraft

Mathematical models[22,23] for predicting the performance and dynamic flight behaviour of several fixed wing aircraft, including the Mirage III and F-111C, and rotary wing aircraft such as the Wessex and Sea King helicopters[14,15] have been developed. These dynamic models have six degrees of freedom and are currently available on the ELXSI computer at ARL.

The programs mostly rely on a large quantity of data, stored in a computer, to specify the aerodynamic and geometric characteristics of each aircraft.

These models have been developed for aircraft and cannot be applied directly to towed targets.

4.3. Mathematical Model Validation

The fixed and rotary wing aircraft mathematical models referred to in section 4.2 have been validated against experimental results. Computer programs, currently available on the ELXSI computer at ARL, have been developed to assist in this validation. These programs use system identification techniques to extract aerodynamic information from flight test data, as well as compatability checking methods for checking flight dynamic test data where there may be errors such as systematic bias and scale factor errors, not usually taken into account in computer simulation studies. Digital filtering techniques have also been developed to remove noise from flight test data.

With some modification, these programs could also be used in validating mathematical models of towed targets.

5. CONCLUDING COMMENTS

Several mathematical models have been developed that are directly applicable to towed targets. There has been some duplication of work mostly caused by personnel not being available to work on the program on a longer term basis and by the particular nature of the task.

The three dimensional dynamic model (section 3.2) is the most capable but it has not been validated, it is not currently available for use on a computer, and numerical stability problems have been experienced. The dynamic models simulating deployment without controlled cable payout[3] (section 2.5) and with controlled cable payout[4] (section 2.6) are also quite capable compared with the three dimensional model, but they are only two dimensional, they have not been validated and they require numerical factors to make the programs run.

The quasi-static model, which takes into account cable payout, and cable elasticity and stability in a simple manner, can be considered the most suitable model currently available to meet Australia's shorter term engineering design requirements, but may not be adequate for longer term needs. However, like the other models numerical stability problems have occurred and it also requires numerical factors to make it run.

All of the models have deficiencies and they are not applicable to all types of towed bodies. Thus, they cannot be regarded as providing a complete design approach for general towed target systems.

The major deficiencies in the codes can be summarised as:

1. the programs rely on known or assumed steady state aerodynamic characteristics for the target and cable, and dynamic effects are not considered;

2. the towed body system is assumed to operate in stable flow and gusts and other unsteady aerodynamic effects have not been taken into account;

3. stability of the towed body and cable has not been modelled adequately and stable operating boundaries cannot be estimated;

4. the codes are not applicable to transonic or supersonic flight regimes;

5. the deployment and recovery phase of flight cannot be modelled accurately when the target is close to the towing body;

6. difficulties have been experienced with numerical techniques particularly when the curvature of the cable is large;

7. body pitching and rotation effects are not taken into account;

8. the flapping motion of banner type targets has not been considered and their stability cannot be assessed;

9. non-circular cables cannot be assessed with the programs in their present form.

10. none of the programs are well documented and user's manuals are not available, so problems must be expected if others attempt to use them.

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APPENDIX 1

TONIC AND TURRAMURRA TOWED TARGETS

The Tonic Mk2 target has a cylindrical body with a tapered and rounded nose, and is approximately 1.1m long. It has short rectangular wings with a NACA 0012 section located near the centre of the body, flat cruciform tail surfaces which can be preset to a small angle of attack, and is towed from its C of G. It was designed to fly below and behind the tug with no lateral separation. The tow weighed about 17 kg (38 lbs) and was trimmed to fly nose down, the vertical separation being changed by altering the downward lift. The towing cable, which was a single strand of stainless steel wire with a diameter of 1.2 mm (0.049 ins) and a breaking strain of 210 kg (460 lb), is attached to the top of the cylindrical fuselage in the plane of symmetry.

Tonic Mk5 is the same as Mk2 except that the cable attachment point can be rotated away from the plane of symmetry by up to 20^{o} in either direction. The horizontal component of lift produces lateral separation and enables dual laterally separated targets to be presented.

Turramurra is essentially a twice size version of Tonic Mk2 weighing about 69 kg (152 lb).

Tonic and Turramurra targets have been used with the Jindivik and Meteor target aircraft respectively.

APPENDIX 2

HIGH PERFORMANCE AERIAL TARGET SYSTEM (HIPATS)

HIPATS-1

The first version of the High Performance Aerial Target System, HIPATS-1, was developed in Australia in the late 1970's.

HIPATS-1, is an air-to-air gunnery target system in which fabric/mesh visual augmentor panels are trailed from a support structure. It has three main elements, the canister (non-jettisonable), visual augmentor target, and the tow cable (approximately 300m (1000 ft)). The canister which is about 2.7m (9 ft) long houses the target electrical control and test module, target ejection device, and target tow/release unit. The furled target and packed tow cable are stowed in the canister prior to launch. The system is carried externally, for example on the bomb beam on the Mirage 111 aircraft.

On receiving the launch command the canister control system ejects the furled target from the rear of the canister using an explosive charge and air drag separates the target from the aircraft. Cable payout is uncontrolled, and when it is fully paid-out the target is suddenly accelerated ('snatched') up to the speed of the aircraft and taken in tow. Furling straps are removed from around the target allowing air flow to effect deployment. The target assumes a cruciform shape and consists of a central staff which acts as the hinge point from which four radial arms are deployed from which the rectangular target panels stream.

The panels are treated to enhance visual acquisition with a luneberg lens attached to the rear of the central staff to obtain satisfactory radar reflectivity. Once deployed the target is ready for gunnery practice.

On completion of practice the target and tow cable are released from the canister allowing the cable and target to fall to the ground.

HIPATS-1A

HIPATS-1A is an improved version of HIPATS-1 and it mainly allows a slightly redesigned target which now has a lower terminal mass to be deployed at a higher aircraft speed.

The target is now packed in a streamline container, called a 'sabot' which is ejected from the canister by an explosive charge. The sabot flies back withdrawing the unrestrained tow cable from the canister until the entire cable is deployed. As the sabot is taken in tow its shells are released and the target is deployed in the same way as HIPATS-1.

The increased deployment speed will lead to increased cable loads, but packing the target in the sabot should reduce drag accordingly. If the sabot produces lift, the cable will be straighter and lower drag will result, but it may also reduce the snatch time and therefore increase the loads during snatch.

HIPATS-2

The basic configuration is similar to HIPATS-1A except that now the tow wire is wound on a drum fixed in the canister. On deployment a module containing the target and appropriate scoring and electronic control equipment is ejected from the canister and glides back a few lengths (4 to 5m (13 to 16 ft)) behind the canister where it is halted by a shock strap (tear webbing) to fly at the speed of the aircraft. After a short period (approx. 5 sec) the cable is payed out from the drum in a controlled manner and the module moves aft until the preset length is payed out. The target is then deployed from the module.

A lanyard, attaching the target to the module, releases the packing bands from around the packed target and when full separation is achieved the arms of the target are freed and the visual augmentor panels stream aft.

The controlled flyback of the sabot reduces maximum cable tension considerably as there is now no 'snatch' phase of deployment. This allows much higher deployment speeds (of the order of 260 m/s (850 ft/sec)) to be achieved.

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An overview is presented of the design codes developed in Australia, that are directly applicable or related to the Aerodynamics of towed bodies.

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